Thesis/
Reports
Nitzky,
A.

Measurement of Air Ionization in Outdoor Settings

by Alene Nitzky and B.L. Driver

RMS

~~Technical~~ Review Draft

MEASUREMENT OF AIR IONIZATION IN OUTDOOR SETTINGS

by

Alene Nitzky, Doctoral Student
at Colorado State University

and

B.L. Driver, Research Social Scientist
with the USDA Forest Service's
Rocky Mountain Forest and
Range Experiment Station

Fort Collins, Colorado
December 15, 1992

(Final Report for CA-28-C1-570)

ABSTRACT

MEASUREMENT OF AIR IONIZATION IN OUTDOOR SETTINGS

Small air ions, the charged gas molecules naturally present in ambient air, have been linked in past studies to improvements in psychological and physiological well-being. Most of these studies used artificially generated high negative ion concentrations and showed improvements in mood and some physical health conditions, while little research has been done using naturally occurring concentrations of air ions. This study examined concentrations of these ions in different outdoor settings which are considered restorative environments. Measures of air ionization were taken at varying proximities to water and vegetative features of these settings in the field and were found to be accurate. Relationships between naturally occurring concentrations of ions and physical features of restorative outdoor settings were investigated. High levels of negative ions were found in close proximity to turbulent water in both natural and urban settings. Concentrations of negative ions found near water in some natural areas were as high as artificially generated ion concentrations used in previous studies. Findings support further investigation of the restorative effects of air ions in natural settings.

TABLE OF CONTENTS

INTRODUCTION	3
Effects of Small Air Ions	3
Air Ions and Restorative Environments	8
Problems of Measuring Small Air Ions	11
PURPOSE	12
HYPOTHESES	12
THE STUDY DESIGN	13
Problems and Limitations of this Study	17
RESULTS	18
DISCUSSION	20
Effects of Area	20
Effects of Distance	21
Effects of Turbulence	22
Distance x Turbulence Interaction	22
Correlations	23
Comments	23
IMPLICATIONS	25
SUMMARY	25
REFERENCES	27

INTRODUCTION

Small air ions, the charged particles naturally occuring in ambient air, have been linked in various studies to improvements in psychological and physiological well-being. This study examined concentrations of these ions in different outdoor settings which are considered restorative environments. Relationships between naturally occuring concentrations of ions and physical features of potentially restorative outdoor settings were investigated.

Effects of Small Air Ions

Small air ions are electrically charged molecules of common atmospheric gases. When an electron is displaced from one of these molecules by radioactive emissions or natural physical forces such as shearing of water droplets or regional winds, the gas molecule becomes positively charged, creating a positive ion. The displaced electron rapidly collides with another gas molecule and delivers a negative charge to it, creating a negative ion (Krueger & Reed, 1976). Both positive and negative small air ions have been of interest to scientists for their effects on living organisms since the early 1900s (Soyka & Edmonds, 1977; Charry, 1984). Physical studies of air ions have yielded information about ionization conditions in various regions of the world. These conditions are dependent upon weather, topographic features, vegetation, and other natural and man-made phenomena (Krueger & Reed, 1976; Hawkins, 1981; Reiter, 1985). Hundreds of studies to date have examined psychological and physiological effects of air ions on living organisms (Charry, 1984, Krueger, 1985). There is convincing evidence that air ions have significant effects on many behavioral and physiological functions in humans and other animals (Krueger, 1973), despite some studies having come under criticism for lack of consistent methodology, particularly

for failure to maintain adequate controls on electrostatic forces and other physical influences on air ions (Charry, 1984; Yates, Gray, Misiaszek, & Wolman, 1986). Charry (1984) presents a thorough review of studies of behavioral and physiological effects of air ionization, and several patterns of positive effects have emerged.

The serotonin hypothesis of ionization, developed by Krueger and colleagues seeks to explain the physiological mechanisms by which air ions work (Krueger, Andriese & Kotaka, 1963). Based on studies of laboratory animals, they reasoned that positive air ions cause accelerated release of the neurotransmitter serotonin in body tissues, while negative ions accelerate its breakdown. Serotonin is involved in many physiological functions, including control of mood, sleep, pain, and arousal (Carlson, 1991).

High levels of circulating serotonin are linked to bronchoconstriction and increased respiratory rate (Krueger and Smith, 1960a), and decreased levels of urinary breakdown products of serotonin have been linked to depression (Carlson, 1991). It follows that breakdown of serotonin would be helpful in persons suffering from respiratory ailments and certain emotional disorders.

Krueger and Smith (1960a) conducted animal studies and linked positive ion exposure to decreased tracheal ciliary movement, increased respiratory rate, and constriction of blood vessels in the tracheal wall. Intravenous administration of either iproniazid or serotonin produced similar effects. Iproniazid increases serotonin levels by blocking the enzyme that breaks the neurotransmitter down (Carlson, 1991). Upon repeating this study with negative ions, decreased concentrations of serotonin were found in tracheal tissues and the opposite effects of positive ion exposure were found (Krueger

& Smith, 1960b). This was followed by administration of reserpine, a drug which blocks serotonin production (Carlson, 1991), and effects similar to those of negative ion exposure were found. Other drugs enhancing and blocking serotonin production were also administered to the animal subjects in these two studies which reproduced these same effects, thereby supporting the serotonin hypothesis (Krueger & Smith, 1960a; 1960b).

While the serotonin hypothesis of air ionization has been accepted by some (Krueger & Reed, 1976; Soyka & Edmonds, 1977), it is still controversial because of the problems with consistent methodology across studies (Charry, 1984). Despite this controversy, in several studies, convincing patterns of improvements in hospitalized subjects exposed to negative air ions have been found. These patients include burn victims (Kornblueh, 1961), people with respiratory ailments (Wehner, 1984) and those with various psychological disorders (Krueger & Sigel, 1978).

Although not all air ion research is related to the serotonin hypothesis, there is growing of evidence which supports the beneficial effects of negative air ions. Epidemiological data indicate that the weather conditions of the Chinook, Santa Ana, Sharav, Foehn, and other wind patterns in different regions of the world are linked to various degrees of affective disorders, surgical complications, general malaise, as well as increases in accidents, crime, and suicides (Muecher & Ungeheuer, 1961; Soyka & Edmonds, 1977; Fletcher, 1988). Fluctuations in both negative and positive ions during these meteorological conditions have been found (Soyka & Edmonds, 1977). In a rigorously controlled study, Charry and Hawkinshire (1981) presented evidence for individual differences in susceptibility to air ionization. Their study was unique in that they used the autonomic lability score (ALS) measure

(Lacey, 1956) of autonomic nervous system function to differentiate normal from ion-sensitive subjects. Most subjects reacted to increases in positive ionization with increased irritability and tension, while only the "positive ion-sensitive" subjects showed actual changes in physiological functions as indicated by skin conductance measures. Performance decrements as measured by reaction time were also found in positive ion-sensitive subjects. According to these findings, it may be necessary to screen subjects for sensitivity to ionization when using physiological parameters and measures of task performance. This differentiation between subgroups of positive ion-sensitive individuals has rarely been used in other studies and both physiological and performance effects of air ionization have been found without it.

In a study of effects of ionization on motor task performance in a work environment, exposure to negative ions was linked to consistent performance levels throughout the day while positive ion exposure resulted in a decline in performance over the same time period, supporting the use of air ionization in the workplace as a performance enhancer (Hawkins & Barker, 1978). Another study found faster reaction times and higher perceived energy on a self-report measure of mood with exposure to negative ion concentrations slightly higher than normal, naturally occurring levels (Tom, Poole, Galla, & Berrier, 1981). Studies of cognitive performance by Baron (1987) showed improvements in memory and performance on a proofreading task with moderately elevated levels of negative ions, and it was suggested that negative ions may influence cognitive performance via an arousal mechanism in an inverted U relationship like the Yerkes-Dodson law (Yerkes & Dodson, 1908) based upon results from a letter-copying task in the same study. Subjects performed more efficiently with slightly to moderately elevated negative ion concentrations, but made more

mistakes at higher concentrations.

High and moderate levels of negative ions were linked to increased aggression in Type A individuals in a study which separated subjects into groups by personality types A and B (Baron, Russell, and Arms, 1985). In this study, elevated negative ion levels positively enhanced moods in both types A and B personalities, but type A individuals also showed increased aggression.

Negative ions have also been associated with improvements in cognitive performance. In a recent study by Morton and Kerschner (1990), elevated levels of negative ion exposure in normal-achieving and learning-disabled children resulted in superior listening task performance over non-ion-exposed controls. In an earlier study these authors contended that negative ion exposure resulted in increased cortical functioning via decreased serotonin levels as an explanation for their findings of improved memory and listening skills in learning-disabled and mentally retarded children (Morton & Kerschner, 1984). In studies of rats, negative ions have also been associated with increased arousal as measured on the EEG, increased vigilance, and improved avoidance task performance (Olivereau, Lambert, & Truong-Ngoc, 1981).

More support for the serotonin link to effects of air ionization has come from research on respiratory disorders, particularly in children with asthma. Serotonin has an effect on bronchial tone and is responsible for a bronchoconstrictor effect (constriction of bronchial tissues) (Ben-Dov, Amirav, Shochina, Amitai, Bor-Yishay & et al, 1983). Asthmatic children exposed to positive ions experienced significantly aggravated symptoms (Lipin, Gur, Amitai, Amirav, & Godfrey, 1984). It has also been shown elsewhere that negative ion exposure results in decreased bronchoconstriction because of a reduction in serotonin levels (Krueger & Smith, 1962; Krueger & Reed, 1976).

Hawkins (1981) conducted a study in an urban office setting where a high incidence of discomfort and malaise was reported among workers. The setting was found to be depleted in small air ions, and a negative ion generator was introduced to the office on a double-blind basis. Significant decreases in complaints of headaches, nausea, and dizziness resulted among workers on all shifts with negative ions, particularly among night shift workers. The use of air conditioning and forced air ventilation systems as well as video display screens and other sources of static electricity alter the indoor concentration of air ions, and indoor environments have been found to contain only 10 percent of the normal outdoor air ion concentration (Hawkins, 1981). The use of air ion generators has been advocated by many who believe that a low level of ionization contributes to discomfort, and the above study (Hawkins, 1981) supports this hypothesis. There is also evidence that air ionization may have effects on symptoms of mental disorders. Psychiatric patients exposed to negative ions showed significant decreases in symptoms of depression, anxiety, insomnia, and other psychosomatic complaints (Deleanu & Stamatiu, 1985).

Studies of air ionization have been part of a broad range of behavioral and physiological research. Considerably more attention has been paid to the effects of negative ions than positive ions, as negative ions appear to be more beneficial. There are definite patterns of agreement that air ions have effects on mood, well-being, and physiological functions, particularly in the findings of the effects of ions on arousal and serotonin-related mechanisms.

Air Ions and Restorative Environments

Recreation may be described as a process of mental and physical rejuvenation or restoration. A growing number of studies examining benefits

of leisure in natural settings have emerged (Driver, Brown & Peterson, 1991), and there is active interest in finding physiological and psychological measures of these benefits (Ulrich, Dimberg & Driver, 1991). This direction of leisure research in natural settings is continuing at a time when the technological age has resulted in more work and recreational pursuits occurring in man-made environments (Yehl, 1991). The effects of long-term exposure to man-made environments have been reported to contribute to illness (Driver & Greene, 1977). The typical American spends 80 percent or more of his/her time indoors (Comptroller General Report to Congress, 1980) and the effects of long-term exposure to indoor environments in modern buildings now include newly recognized health problems such as Sick Building Syndrome and Video Operator's Distress Syndrome (Norback & Edling, 1991; Yehl, 1991).

Stress encountered during daily activities may build up over time, resulting in mental fatigue, decreased work productivity, and lowered resistance to stress despite the body's ability to adapt to chronic stress (Bell, Fisher, Baum, & Greene, 1990). Escape to a restorative setting is one way in which accumulated mental fatigue and physical manifestations of stress may be reduced (Olmsted, 1865; Hartig, Mang & Evans, 1991).

Several evolutionary perspectives have emerged which share the common notion that since humans evolved in natural settings, they are somewhat tuned to natural rather than urban settings (Ulrich et al., 1991). Since urban settings are relatively new in the evolutionary span of human existence, and the technological age has only existed for a few decades, proponents of evolutionary theories might argue that sufficient time has not passed for humans to biologically adapt to their technologically-altered surroundings. These perspectives support the notion that our bodies are still "in tune" with

the types of natural settings in which homo sapiens evolved, and they are being forced to adapt to the unnatural environment we have created (Stainbrook, 1968). Humans may have an evolved predisposition to respond positively to natural settings (Ulrich et al., 1991) and particularly to those areas which may have been favorable to survival and well-being (e.g. where food and water were available) (Stainbrook, 1968; Ulrich, 1983; Kaplan & Kaplan, 1989; Ulrich et al, 1991). When stressed, humans react more favorably to natural settings than to urban environments for stress reduction and restoration (Ulrich & Simons, 1986).

A psychoevolutionary theory of restoration (Ulrich, 1983) brought a psychophysiological perspective to the concept of stress recovery through exposure to natural settings. This theory considers aesthetic preferences, emotional responses, and physiological arousal components of the restorative process. That process serves to return energy to the organism for future environmental demands, enhance well-being, cause positive affective states and decrease arousal and feelings of fear (Ulrich, Simons, Losito, Fiorito, Miles & Zelson, 1991).

The physical properties of restorative outdoor environments may differ greatly from those of man-made environments. According to studies of visual perceptions of outdoor settings, areas may be categorized as "natural" if features like vegetation and water dominate the landscape without the obvious presence of buildings and other man-made features (Ulrich, 1983). Presence of vegetation, clean natural running water, and good air quality are some features which may contribute to a restorative outdoor experience. Air ion concentrations are higher in many water-proximal and vegetated areas (Krueger & Reed, 1976; Gray, 1991). The presence of water is highly attractive to many

recreationists (Clark & Downing, 1985). People who recreate in areas with elevated levels of air ionization might receive restorative benefits as a result of exposure to these high ion concentrations.

Problems of Measuring Small Air Ions

Electrostatic properties of small air ions make them difficult to measure, however, there is reason to believe that experiments can be conducted successfully given attention to certain environmental conditions including dust, pollution, electrical fields, and weather patterns (Yates, et al., 1986). A major criticism of many air ionization studies is that very high artificially generated levels of ionization were used; conditions that would never be encountered naturally (Reiter, 1985). While one would not expect negative ion levels to reach the very high levels produced in artificial laboratory settings, the question must be raised: Are humans sensitive to the levels of air ions occurring under natural conditions? Charry (1984) suggests they are not, however, under naturally occuring ambient conditions. There is, however, evidence to suggest otherwise (Hawkins & Barker, 1978; Tom, et al., 1981). Under certain naturally occuring phenomena, much higher than normal levels of air ions are present. A waterfall, for example, produces high levels of negative ions from the shearing of water droplets (Krueger & Reed, 1976). There may also be an effect on air ionization from some types of vegetation, e.g. in the immediate area surrounding sharp conifer needles (Gray, 1991). Finally, certain weather patterns characterized by hot, dry winds may also substantially increase the level of ambient air ionization (Krueger & Reed, 1976).

In several previous air ionization experiments with human subjects, the air ion concentration approximated normally occurring conditions (Hawkins &

Barker, 1978; Tom et al., 1981; Charry, 1984), so it appears that some effect may be measurable under specific natural conditions where ionization levels are elevated. Reiter (1985) compiled several years of recordings at stationary locations in Europe, recording weather patterns, ion concentrations, and ratios of positive to negative ions. This is one of the few studies of air ions in outdoor settings. Presently, we know of no studies conducted in which direct measurements of air ionization were made in different proximities to water and vegetation under conditions which would commonly be encountered in outdoor recreation settings. There have been few studies examining microclimatic patterns of ionization while controlling for proximity to vegetation and water. As part of a program of research in understanding the restorative and other benefits of natural settings, this study is an attempt to determine if measurable patterns of air ionization are found in commonly encountered outdoor recreation settings. If these patterns are found in varying proximities to water and/or vegetation, further studies of air ions and their psychophysiological effects on the users of these settings are warranted.

PURPOSE

The purpose of this study was to test small air ion gradients in various field settings and to find patterns of these gradients in different proximities to water and vegetation.

HYPOTHESES

The following hypotheses were tested:

1. As proximity to water increases, there will be an increase in negative ions and a decrease in positive ions.

2. As proximity to vegetative cover increases, there will be an increase in negative ions and a decrease in positive ions.

3. Urban areas will have lower levels of negative ions and higher levels of positive ions than natural areas.

4. Highly turbulent bodies of water will create higher concentrations of negative ions than non-turbulent water.

5. As the amounts of vegetative ground cover and foliage on site increase, there will be an increase in both positive ions and negative ions, and as relative humidity increases up to 70 percent, there will be an increase in negative ions and a decrease in positive ions.

THE STUDY DESIGN

A quasi-experimental field design was employed, using nine different sites for collection of air samples for ionization counts. The sites were differentiated by three different categories: Urban Vegetated, Urban Water-Proximal, and Natural Water-Proximal. Urban sites were characterized by mostly man-made structures and landscapes (e.g. buildings, parking lots, traffic, concrete fountains, and parks). Six different urban sites were selected, all located within the city of Fort Collins, Colorado at an elevation of approximately 5000 feet (1520 m), with one site on the Colorado State University campus within the city. Three natural sites were selected within 30 miles of the city. Natural sites contained predominantly vegetation and natural bodies of water, with few man-made structures nearby and minimal traffic. Vegetated areas were differentiated from water-proximal areas in that they contained vegetation but did not have a natural or man-made body of water in the immediate vicinity (within 0.1 mile radius). Water-proximal areas were those areas with a body of water as a prominent physical feature and also contained vegetation. There were two vegetated and four water-proximal sites in urban areas, and three water-proximal natural sites. Natural Vegetated areas without water were not sampled in this study because

of problems with access and equipment mobility. Table 1 contains a description of the nine sample sites. Permission was obtained to conduct the experiment from the City of Fort Collins Parks and Recreation department, the Colorado State University Grounds department, Colorado State Parks Department, and the USDA Forest Service. All recordings were taken between July 8 and August 9, 1991, on fair weather days without precipitation or excessive wind. All recordings were made within the temperature range of 20 and 30 degrees C and not more than 70 percent relative humidity.

The dependent variable was concentration of positive or negative small air ions per cubic centimeter. Control variables were degree of water turbulence, amount of vegetative ground cover and overhead foliage cover, relative humidity, and distance from body of water or dense vegetation using two different proximities; less than 25 feet). Drawing on the suggestion that ionization levels might be elevated in close proximity to water and vegetation (Krueger & Reed, 1976), we hypothesized that a gradient would exist in ionization levels with increasing distances (Gray, 1991). Our reasoning was that physical forces causing higher levels of negative ions (e.g., shearing of water droplets) would be more prominent in the immediate vicinity of water, especially turbulent water, and levels of negative ionization would drop off with distance from water as a result of other forces in the environment (e.g., dilution of negative ion concentration by surrounding air; Gray, 1991). Twenty-five feet was chosen because of the physical features of the sites. In vegetated areas, low hanging foliage sometimes interfered with the ability to move the equipment, and in water-proximal areas, banks of rivers and streams were often very steep or rocky making equipment access impossible. Beyond 25 feet, a spray from the turbulent water conditions could no longer be

perceived.

As part of the exploratory nature of this study, we were particularly interested in the effect of water turbulence on ionization in the immediate vicinity of the turbulent water. Although it is known that shearing of water droplets and waterfalls produce high levels of negative ions (Krueger & Reed, 1976), we were unable to find any documentation of how much turbulence was necessary to create this effect. For simplicity, it was decided to select just two general categories of "turbulence" to represent different types of water conditions commonly encountered by users of water based outdoor recreation areas. Two different turbulence levels were selected based on our judgment of the relative calmness of the water. Water with very little movement and no apparent direction of flow and few ripples except for occasional surface disturbances from wind or other objects (e.g. a pond) was defined as non-turbulent water. Flowing water having an obvious direction of flow with a calm current (no spray, eddies, or rapids) was also included in this category. Highly turbulent water was characterized by rapids and was moving fast enough to produce a spray or waterfall effect. Size of the body of water was not a consideration here.

The sites at which air ion levels were measured were located in urban parks, a college campus, and natural areas easily accessible by car within a short drive from the city. The sites were chosen for their ease of accessibility with the equipment, their frequent use by recreationists, and the diversity of bodies of water and vegetation types, which covered a range of recreation areas available within and nearby the city. Recordings were made of the following variables for site identification and information purposes: location of site, time of day, day of week; weather conditions

including temperature, relative humidity, wind speed, and wind direction; physical features of the setting including vegetation type, slope, aspect, and terrain; and presence of potential electrostatic influences including vehicular traffic, number of cars and people, presence of ground moisture, metal objects, powerlines, buildings, and sprinkler heads on site.

On each site, between four and eight different air samples were taken in 25 foot increments away from the place of origin. The place of origin was a location as physically close as a person could come to a group of trees, a clump of dense vegetation, or the edge of a body of water without being physically in the water. While eight samples were planned to be collected at each sample site, the actual number that could be taken was determined by characteristic of the physical environment. For example, man-made structures such as bike paths, roadways, buildings, and parking lots were used as boundaries to sample sites.

The measures of air ions were made using portable instruments that were powered by a portable Honda EM650 gasoline-powered electrical generator. The equipment was mounted and transported on a small wagon with a wooden platform, on which the ion counter and electrometer were arranged. The generator was placed downwind from the equipment station at all times, at least 50 feet away from the nearest sampling point to avoid problems with exhaust blowing towards the air intake of the ion counter. All equipment was grounded to a copper grounding stake, which was placed in the ground at each location. Grounded extension cords were used to carry the current from the generator to the mobile equipment. All measurements were taken with the equipment mounted at the same height above ground while resting on the platform (approximately 2.5 feet above the ground).

The Model Beckett Ion Counter and Mobility Discriminator (American Environmental Systems, Boulder, CO) was used to collect samples from the ambient air. Only small ions (diameter less than .005 micrometers) were sampled. Recordings of air ion particle charges were obtained with a Keithley Model 616 Electrometer, which gives a reading in amperes, converted to ions/cm^3 with a conversion factor of 3.36×10^4 (American Environmental Systems, 1987). Between individual recordings the electrometer was reset to zero to insure accuracy, and the air intake continued to flow to provide a fresh air sample every time. Each air sample was recorded only after the reading had peaked and then stabilized (American Environmental Systems, 1991). The electrometer has a narrow climatic operating range between 20 and 30 degrees Celsius and no more than 70 percent relative humidity. For this reason, sampling was limited to certain hours of the day and certain weather conditions. The ion concentration recordings, read in amperes from the electrometer, were later converted to numbers of ions per cubic centimeter of air volume, and a ratio was determined by dividing the number of positive ions by the number of negative ions.

To obtain recordings of weather conditions, an Assman Psychrometer was used to read dry bulb and wet bulb temperatures, and a table was used to determine relative humidity from these readings (U.S. Department of Commerce Weather Bureau, 1963). A battery powered anemometer was used to determine wind speed and direction.

Problems and Limitations of this Study

Several problems were encountered in the process of measuring ionization. Occasionally the presence of a group of park users physically limited the extent to which sampling could be continued. The summer weather conditions in

Fort Collins also made it necessary to sample only between about 9:00 am and 2:00 pm each day, in order to stay within the climatic range of the electrometer. Also, recently irrigated vegetated areas had to be avoided as they caused erratic readings on the electrometer. The other problems encountered during data collection were with people coming too close to the air intake of the ion counter, and any air disturbance caused by wind gusts, traffic, or flying objects (e.g. birds, frisbees) would disturb the equipment, so it was necessary in those cases to obtain new readings. Most readings could be obtained in 5 to 10 minutes unless an air disturbance occurred. It was also necessary to watch for fast-moving afternoon thunderstorms to avoid being caught by the rain or weather disturbance. The ion counter was calibrated periodically according to manufacturer's instructions (American Environmental Systems, 1991) with a small desktop unit provided with the instrument. The electrometer was calibrated by the supplier immediately prior to our use. Equipment maintenance and minor repairs were necessary along with constant checks on the electrical connections between the instruments.

A limitation of this study was the small number of observations made in some areas. Certain locations were more easily accessible for our equipment depending upon physical features of the sites. For this reason, more data were recorded in urban vegetated areas than in either urban or natural water-proximal areas.

RESULTS

Recordings of air ion concentrations in this experiment were similar to those reported previously by Reiter (1985) under similar conditions. Reiter reported average concentrations of 0 to 1250 positive ions/cm^3 and 0 to 800

negative ions/cm^3 over time in fair weather conditions at 1780 m above sea level over a 5 year period. In this experiment, average concentrations ranged from 76 to 1056 positive ions/cm^3 and from 74 to 851 negative ions/cm^3 under fair weather conditions.

Oneway analysis of variance was used to estimate the effect of the type of area (urban vegetated, urban water-proximal, or natural water-proximal) on levels of negative or positive air ionization. Across the 3 types of areas, negative ionization was significantly higher in natural water-proximal areas than in either of the two types of urban areas, while positive ionization was highest in urban vegetated areas and lowest in natural water-proximal areas. Post-hoc pairwise comparisons (Tukey's Honest Significant Difference) of the three types of areas revealed no significant differences in negative ionization between urban vegetated and urban water-proximal areas ($p < .05$). Table 2 contains a summary of these results.

Analysis of variance was then used to estimate effects of distance and/or turbulence categories on negative and positive ionization in each of the three types of areas. In urban water-proximal areas, there was a distance by turbulence interaction for negative ionization only. In this case, the non-turbulent conditions did not appear to alter the levels of ionization with increased distance from water and highly turbulent water conditions showed a sharper decline in negative ionization more than 25 feet away from water. In natural areas, there was a somewhat less steep decline in negative ionization at the greater distance in the highly turbulent water conditions, but there was no interaction between distance and turbulence. Negative ionization was significantly higher in close proximity to water and was also significantly higher near highly turbulent water than non-turbulent conditions. Table 3

contains a summary of distance effects, and Table 4 shows distance by turbulence interaction effects. In urban vegetated areas there were no distance effects on either positive or negative ionization. There were no significant correlations between positive or negative ionization and amounts of vegetative ground cover, foliage cover, or relative humidity.

DISCUSSION

Effects of Area

Data were consistent with the hypothesis of differences in ionization levels between urban and natural areas. Natural water-proximal areas had significantly higher levels of negative ions than either of the urban areas. This supports previous findings of lower levels of negative ions in urban areas due to pollution and electrostatic forces such as powerlines and man-made structures (Yehl, 1991). As expected, negative ionization was highest in natural areas due to a relative absence of these forces. Post-hoc pairwise comparisons showed urban vegetated and water-proximal areas were not significantly different in terms of overall mean negative ionization levels. These results are not surprising because all urban sites were fairly homogeneous in character. They were all located within the city and were similar in the types of structures present on site and in their surrounding environments, the only difference being the presence of water. Likewise, urban areas were expected to have higher levels of positive ions than natural areas, and the findings show this exact pattern. Previous reports of positive ion concentrations are supported by these results. Electrostatic forces and pollution probably influenced ambient levels of positive ionization.

Effects of Distance

In urban vegetated areas, negative and positive ions were not significantly different across the distance categories. Furthermore, in the greater than 25 foot zone, post-hoc analysis of variance of four 25 foot distance increments (up to 100 feet) revealed no significant differences in ionization levels with increased distance, hence no gradient or pattern emerged with increased distance from vegetation. Therefore, we did not reject the null hypothesis of no effects of distance on ionization in vegetaed areas. High levels of ionization have been found in close proximity to coniferous vegetation in the past (Gray, 1991). The vegetation on the sites sampled here was predominantly deciduous, consisting of mostly cottonwood trees and native small plants and grasses, so it is possible that patterns of ionization may be influenced differently depending on the type of vegetation present.

In natural water-proximal areas, negative ionization was significantly higher less than 25 feet from water than at greater distances. Positive ionization was not significantly different across distance categories but did increase slightly. This distance effect on negative ionization suggests a relationship where a sensitive or "critical" zone less than 25 feet from the body of water has higher levels of negative ionization, but the effect does not continue beyond this point. Post-hoc analysis of variance was performed on the distances in this less-proximal zone in 25 foot increments to identify any patterns of decreasing levels of ionization, but no significant pattern emerged. The level of ionization remained the same with varying distances from water.

Effects of Turbulence

There was a significant effect of turbulence on negative ionization in

natural areas in the expected direction. Negative ionization levels were nearly twice as high under highly turbulent conditions than for non-turbulent conditions (Table 4). We reject the null hypothesis of no difference in negative ionization across turbulence levels. These findings of increased negative ionization with greater water turbulence supports past research reported by Krueger and Reed (1976). The turbulent flow produces more energy for shearing of water droplets.

Distance x Turbulence Interaction

In urban water-proximal areas, there was an interaction between distance and turbulence categories. The effects of distance and turbulence were in the expected directions only for negative ions. Negative ions were highest in close proximity to water and decreased significantly after 25 feet. For positive ions, no significant effects of turbulence or distance were observed for either natural or urban areas. Although the interaction was significant only in urban areas, it is important to separate distance and turbulence effects in both urban and natural areas since the categories were somewhat subjectively chosen.

Under non-turbulent conditions, negative ionization stayed relatively stable with increased distance from water. In highly turbulent conditions, a greater decline in ionization was observed, with urban areas even more dramatic than natural areas. This phenomenon could be explained in several ways. First, electrostatic forces in urban areas could counteract the increased levels of negative ionization as soon as the air leaves the critical zone. Natural areas are not subject to the same magnitude of electrostatic forces, so negative ionization would drop off more slowly. Second, the natural areas sampled here had a much higher level of negative ionization at

further distances from water, thus making the decrease appear to be less dramatic. Again, since these categories of distance and turbulence are somewhat subjective, no inferences can be made until further studies are done. Additional measurements under more highly controlled turbulence conditions will be necessary before making any conclusive statements about the nature of this interaction.

Correlations

No significant correlations were found between vegetative ground cover, foliage cover, or relative humidity. This is not surprising since there were no effects of distance from vegetation on ionization levels. Also, relative humidity, a passive physical force by comparison to the shearing of water droplets in a flowing stream, does not appear to be effective in altering levels of air ionization. It was expected that the amount of moisture in the air would influence concentrations of air ions, but this did not happen. More active physical forces may be necessary to create the energy needed to remove electrons from gas molecules. Data were not consistent with a hypothesis of a correlation between ionization and any of these variables.

Comments

The two proximities used in this experiment were chosen for ease of mobility of the equipment and the physical characteristics of the sites. For this reason, the true distances at which the concentrations of air ions changed are not known. The closest proximities to water may represent areas in which water-based recreational activities (e.g. fishing, rafting) take place. Many land-based activities (e.g. hiking, hunting) occur in the greater proximities to water. In vegetated areas without water, the proximities are less representative of those areas encountered by recreationists, although it

is possible to imagine being in areas with different densities of vegetation. This experiment was not intended to determine exactly where in the physical environment these phenomena occur; rather, it was intended to determine whether any concentration gradients exist in these areas. It is recommended for any future field studies that subjects be taken to within 25 feet of water in order to study effects of ionization. Further measurements are needed to determine the exact nature of the relationship between distance and ionization.

Except for the effect of area, no significant effects for positive ions were found. Few studies have been done with positive ionization as a dependent measure. Since negative ions appear to be the mediators of beneficial effects, more attention was focused on negative ions in this study.

There has been much discussion in the literature about the problems of electrostatic influences on air ion measurements (Charry, 1984). Efforts were made to control for the influences of weather conditions, presence of metal objects, powerlines, moisture on the ground, buildings, electronic equipment, traffic, and high levels of air pollution. Analysis using Pearson correlations failed to reveal any significant correlations of these variables with ionization levels. It is not known to what extent these influences may have affected the data. The problem of controlling for extraneous variables in any field study was compounded by the difficulties of measuring objects so easily influenced by physical properties of the environment. For these reasons, several steps were taken to insure consistency in the conditions of the physical environment for data collection. A narrow range of weather conditions existed during sampling as necessitated by the equipment, sites free from the influences of powerlines and other electrostatic forces were

selected, equipment was grounded at all times and was recalibrated to zero after each measurement, and all air samples were taken at the same distance above the ground.

IMPLICATIONS

Since high levels of negative ions are found in close proximities to water, further studies of some of the previously reported psychological and physiological efffects of ionization under these natural conditions are warranted. Measurement of mood and physiological parameters of participants in recreational activities centered around water (e.g. fishing, rafting) might be studied for further information about some of the benefits that could be derived from exposure to high naturally-occurring negative air ion concentrations. If high levels of air ionization do have an effect on such psychological and physiological parameters as mood, blood pressure, and muscle tension, the restorative effects of these types of activities might be partially explained by air ion exposure.

Other implications for the use of plants and highly turbulent waterfalls and artificial fountains in urban and indoor landscaping to raise ionization levels exist if those concentrations of ions are shown to positively impact mood and other physiological functions. Exposure to naturally high levels of negative ions during the workday and during leisure time could increase productivity at work and bring about better health and well-being which extends beyond the workplace to the home and to society. Implications also exist for natural resource planning and management decisions pertaining to recreation in water-proximal areas. If greater health benefits are shown in people who recreate in areas with water (e.g. rivers with natural flow

conditions and rapids) it might be more advantageous for natural resource decision-makers to plan for and manage areas with these attributes.

Since a few studies have already shown psychological and physiological benefits from ionization, we recommend studies of these effects under controlled laboratory conditions, where ionization can be held at levels approximating those found in natural environments. Other studies could be conducted on recreationists participating in water- and non-water-based activities to identify any measurable difference in mood and physiological parameters between those exposed to high and average levels of air ionization. The question to be answered is: Does air ionization have any influence on the benefits derived from leisure activities in certain types of natural environments?

SUMMARY

Air ionization can be measured accurately in the field with portable equipment and attention to physical and electrostatic properties of the surroundings. Positive and negative air ion concentrations measured in the field were in the ranges of previously reported data measured under similar conditions. Natural water-proximal areas had the highest levels of negative ions followed by urban water-proximal and vegetated areas. Positive ionization was highest in urban vegetated areas followed by urban and natural water-proximal areas, respectively. Concentrations of negative ions are higher in both urban and natural water-proximal areas at distances less than 25 feet from a body of water, beyond which concentrations decrease abruptly and stabilize. Positive ion concentrations do not change across two categories of distance from water or vegetation, and negative ion

concentrations do not change with increased distance from vegetation in urban vegetated areas. In natural water-proximal areas, negative ion concentrations are higher under highly turbulent water conditions than under non-turbulent conditions. In urban water-proximal areas less than 25 feet from highly turbulent water, negative ion cncentrations are very high but drop off significantly with increased distance from water. Under non-turbulent conditions, this decrease in negative ionization across distance is very small. For the range of conditions sampled, there were no relationships between amount of vegetative ground cover, foliage cover, or relative humidity and concentrations of negative or positive ions.

Further studies of air ionization may determine whether participation in recreational activities under high negative ion concentrations is more beneficial. If mood and other health parameters are found to be improved upon exposure to these naturally elevated levels of ionization, implications exist for the use of natural "ion generators" such as artificially landscaped waterfalls in urban workplaces to improve productivity, health, and well-being. Other implications exist for natural resource planning and management decisions pertaining to recreation in areas with water attributes.

REFERENCES

American Environmental Systems. 1987. Model Beckett Air Ion Counter and Mobility Discriminator. American Environmental Systems, Inc. Boulder, CO.

American Environmental Systems. 1991. Personal communication, July 9.

Baron, R.A. 1987. Effects of negative ions on cognitive performance. Journal of Applied Psychology, 72, 131-7.

Baron, R.A., Russell, G.W., & Arms, R.L. 1985. Negative ions and behavior: Impacts on mood, memory, and aggression among

Type A and Type B persons. Journal of Personality and Social Psychology, 48, 746-54.

Bell, P.A., Fisher, J.D., Baum, A., & Greene, T.E. 1990. Environmental Psychology. 3rd edition. Holt, Rinehart & Winston, Inc. Ft. Worth, TX.

Ben-Dov, I., Amirav, I., Shochina, M., Amitai, I., Bor-Yishay, E., & et al., 1983. Effects of negative ionization of inspired air on the response of asthmatic children to exercise and inhaled histamine. Thorax, 38, 584-8.

Carlson, N.R. 1991. Physiology of Behavior 4th ed. Allyn & Bacon, Boston, MA.

Charry, J.M. 1984. Biological effects of small air ions: A review of findings and methods. Environmental Research, 34, 351-89.

Charry, J.M. & Hawkinshire, F.B.W. 1981. Effects of atmospheric electricity on some substrates of disordered social behavior. Journal of Personality and Social Psychology, 41, 185-97.

Clark, R.N. & Downing, K.B. 1985. Why here and not there: The conditional nature of recreation choice. Proceedings-Symposium on Recreation Choice Behavior. General Technical Report INT-184. U.S. Dept. of Agriculture, Forest Service, Intermountain Research Station, 61-70.

Comptroller General Report to U.S. Congress. 1980. Indoor Air Pollution: An Emerging Health Problem. U.S. General Accounting Office Publication No. CED-80-111.

Deleanu, M. & Stamatiu, C. 1985. Influence of aeroionotherapy on some psychiatric symptoms. International Journal of Biometeorology, 29, 91-96.

Driver, B.L., Brown, P.J. & Peterson, G.L. 1991. Benefits of Leisure. Venture Publishing, Inc. State College, PA.

Driver, B.L. & Greene, P. 1977. Man's nature:Innate determinants of response to natural environments. In: Children, nature, and the environment. U.S. Dept. of Agriculture General Technical Report NE-30. 63-70.

Fletcher, R.J. 1988. "Fohn illness" and human biometeorology in the Chinook area of Canada. International Journal of Biometeorology, 32, 168-75.

Gray, F.B. 1991. Personal communication, July 9.

Hartig, T., Mang, M. & Evans, G.W. 1991. Restorative effects of natural environment experiences. Environment and Behavior, 23, 3-26.

Hawkins, L.H. 1981. The influence of air ions, temperature, and humidity on subjective well-being and comfort. Journal of Environmental Psychology, 1, 279-92.

Hawkins, L.H. & Barker, T. 1978. Air ions and human performance. Ergonomics, 21, 273-8.

Hedge, A. & Eleftherakis, E. 1982. Air ionization: An evaluation of its physiological and psychological effects. Annals of Occupational Hygiene, 25, 409-19.

Kaplan, R. & Kaplan, S. 1989. The Experience of Nature. New York: Cambridge University Press.

Kaplan, S. & Talbot, J.F. 1983. Psychological benefits of a wilderness experience. In Altman, I & Wohlwill, J.F. (Eds.), Human Behavior and Environment: Vol. 6. Behavior and the Natural Environment (pp. 163-203) Plenum. New York, NY.

Kornblueh, I. 1961. Brief review of the effects of artificial ionization of the air. Archives of Medical Hydrology, 21, 1-9.

Krueger, A.P. 1973. Are negative air ions good for you? New Scientist, 58, 668-70.

Krueger, A.P. 1985. The biological effects of air ions. International Journal of Biometeorology, 29, 205-6.

Krueger, A.P., Andriese, P.S., & Kotaka, S. 1963. The biological mechanism of air ion actions: the effect of CO2 in inhaled air on the blood level of 5-Hydroxytryptamine in mice. International Journal of Biometeorology, 1, 3-16.

Krueger, A.P. & Reed, E.J. 1976. Biological impact of small air ions. Science, 193, 1209-13.

Krueger, A.P. & Sigel, S. 1978. Ions in the air. Human Nature, 7, 46-52.

Krueger, A.P. & Smith, R.F. 1960a. The biological mechanisms of air ion action. I. 5-Hydroxytryptamine as the endogenous mediator of positive air ion effects on the mammalian trachea. Journal of General Physiology, 43, 533-40.

Krueger, A.P. & Smith, R.F. 1960b. The biological mechanisms of air ion action. II. Negative air ion effects on the concentration and metabolism of 5-Hydroxytryptamine in the mammalian respiratory tract. Journal of General Physiology, 44, 269-276.

Krueger, A.P. & Smith, R.F. 1962. Studies on the effects of gaseous ions on the mammalian trachea. In: Proceedings of the Second International Bioclimatology Congress, Pergamon Press, New York, NY. pp. 498-506.

Lacey, J.I. 1956. The evaluation of autonomic responses: Toward a general solution. Annals of the New York Academy of Sciences, 67, 123-164.

Lipin, I., Gur, I., Amitai, Y., Amirav, I. & Godfrey, S. 1984. Effect of positive ionization of inspired air on the response of asthmatic children to exercise. Thorax, 39, 594-6.

Morton, L.L. & Kerschner, J.R. 1984. Negative air ionization improves memory and attention in learning disabled and mentally retarded children. Journal of Abnormal Child Psychology, 12, 353-65.

Morton, L.L. & Kerschner, J.R. 1990. Differential negative air ion effects on learning disabled and normal achieving children. International Journal of Biometeorology, 34, 35-41.

Muecher, H. & Ungeheuer, H. 1961. Meteorological influence on reaction time, flicker-fusion frequency, job accidents, and medical treatment. Perceptual and Motor Skills, 12, 163-8.

Norback, D. & Edling, C. 1991. Environmental, occupational, and personal factors related to the prevalence of sick building syndrome in the general population. British Journal of Industrial Medicine, 48, 451-62.

Olivereau, J.M., Lambert, J.F. & Truong-Ngoc, A. 1981. Influence of artificial air ionization on the electroencephalogram of the awake rat. International Journal of Biometeorology, 25, 71-5.

Olmsted, F.L. 1865. The value and care of parks. Report to the Congress of the State of California. [Reprinted in R. Nash, Ed. 1976. The American Environment. Addison-Wesley, Reading, MA. pp. 18-24.]

Reiter, R. 1985. Frequency distribution of positive and negative small ion concentrations, based on many years recordings at two mountain stations located at 740 and 1780 m ASL. International Journal of Biometeorology, 29, 223-31.

Soyka, F. & Edmonds, A. 1977. The ion effect. E.P.Dutton & Co, New York, NY.

Stainbrook, E. 1968. Human needs and the natural environment. In: Man and Nature in the City. Proceedings of a symposium of the Bureau of Sport Fisheries and Wildlife. Washington, D.C. U.S. Department of the Interior. pp. 1-9.

Tom, G., Poole, M.F., Galla, J. & Berrier, J. 1981. The influence of negative air ions on human performance and mood. Human Factors, 23, 633-6.

Ulrich, R.S. 1983. Aesthetic and affective response to natural environment. In I.Altman & J.F. Wohlwill (Eds.), Human behavior and environment:Vol. 6. Behavior and the natural environment (pp. 85-125). Plenum, New York, NY.

Ulrich, R.S., Dimberg, U. & Driver, B.L. 1991. Psychophysiological indicators of leisure benefits. In Driver, B.L., Brown, P.J.& Peterson, G.L.(Eds.), Benefits of Leisure (pp. 73-89). Venture Publishing, Inc. State College, PA.

Ulrich, R.S. & Simons, R.F. 1986. Recovery from stress during exposure to everyday outdoor environments. In: J. Wineman, R. Barnes & C. Zimring, Eds. Proceedings of the Seventeenth Annual Conference of the Environmental Design Research Association. EDRA, Washington, D.C. pp. 115-22.

Ulrich, R.S., Simons, R.F., Losito, B.D., Fiorito, E., Miles, M.A., & Zelson, M. 1991. Stress recovery during exposure to natural and urban environments. Journal of Environmental Psychology, 11, 201-30.

U.S. Department of Commerce Weather Bureau. 1963. Relative Humidity and Dew Point Table. Publication No. TA 454-0-1B.

Wehner, A.P. 1984. Stimulation of interferons and endorphins/ enkephalins by electro-aerosol inhalation: An experimental approach for testing an expanded hypothesis. International Journal of Biometeorology, 28, 47-53.

Yates, A., Gray, F.B., Misiaszek, J.I.& Wolman, W. 1986. Air ions: Past problems and future directions. Environment International, 12, 99-108.

Yehl, J.E. 1991. Mitigating the sick building syndrome using a biological model. Unpublished paper. Presented to: Center for Building Performance, School of Architecture, Carnegie-Mellon University, Pittsburgh, Pennsylvania. May 6, 1991.

Yerkes, R.M. & Dodson, J.D. 1908. The relationship of strength of stimulus to rapidity of habit formation. Journal of Comparative Neurology and Psychology, 18, 459-482.

TABLE 1
Description of Sample Sites

Type of Site/Name	Description
URBAN	
Water-proximal	
CSU Library plaza fountain	College campus, concrete plaza with 4 ft high fountain, highly turbulent water, plaza surrounded by small trees
Edora Park Creekside	Urban park, 10 ft wide shallow creek, slight turbulence. Cut grass and large cottonwood trees on sides of creek.
URBAN	
Water-Proximal	
Poudre Trail	Next to Cache la Poudre River, slightly turbulent water, next to concrete bike/running path, native grasses and cottonwood trees on banks of river. Heavy traffic at nearby intersection.
Rolland Moore Park Pond	Shallow pond, about 1 acre in surface, area, non-turbulent water, surrounded by cut grass, small trees.
URBAN	
Vegetated	
City Park Northeast corner	Thickly vegetated with large Trees-spruce, cottonwood, other deciduous trees, thick foliage, cut grass.
Spring Creek Trail	Open field with thick, tall grass, sparse tree cover. Next to bike/running path.
NATURAL	
Water-proximal	
Big Thompson Canyon	Handicapped-accessible fishing pier off highway. Wooden pier built above river, highly turbulent water, natural surroundings, canyon walls.
Lower Poudre Canyon	Picnic area, natural area but Picnic Rock Area just off highway, tall native grass, cottonwood trees, wide, calm river, slightly turbulent water.
Poudre Canyon Mishawaka-Poudre Park Picnic Grounds	Undeveloped fishing areas on lower Poudre river, highly turbulent water, big boulders, rocky terrain, canyon walls, ponderosa pine, cottonwoods. Turnouts off highway.

TABLE 2
Mean Ionization Levels by Area
(ions/cm³)

	Urban Vegetated n=90	Urban Water-Proximal n=39	Natural Water-Proximal n=32
positive	924.1	836.7	704.5
negative	660.8@	702.4@	985.2

@ not significantly different from each other according to Tukey's HSD ($p \geq .05$).

TABLE 3
Ion Concentrations in Different Proximities to Water and Vegetation
(ions/cm^3)

type of area/ions	< 25 feet	25+ feet	p	F
Urban-Vegetated				
positive	984.4	908.6	@	1.61
negative	673.3	710.0	@	.43
Urban Water-Proximal				
positive	892.3	824.7	@	2.17
negative	899.0	609.3	<.01	11.23
Natural Water-Proximal				
positive	640.2	754.5	@	2.16
negative	1153.4	854.4	<.01	11.48

@ not significant.

TABLE 4
Negative Ion Concentrations by Turbulence and Proximity to Water (Interaction)
(ions/cm^3)

type of area/turbulence	<25 feet	25+ feet	p	F
Urban				
non-turbulent	593.1	567.5		
			<.001	61.12
highly turbulent	1816.9	749.3		
Natural				
non-turbulent	595.5	702.3		
			@	1.61
highly turbulent	1571.9	1158.6		

@ interaction between distance and turbulence not significant.